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## The DLAs contribution to the metal content of the high $z$ Universe

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**Abstract.** We investigate the evolutionary history of the Universe's metal content focusing on the chemical abundance of several elements (N, O, S, Si, Fe, Cr, Zn) taken from observational data and predictions from chemical evolution models. The estimated abundances were observed in Damped Lyman  $\alpha$  Systems (DLAs) over a wide range of redshift ( $z \sim 0.5$ – $4.5$ ). These data are compared to predictions of chemical evolution models. Since the nature of the DLAs is uncertain, they are represented by two class of models: models with galactic winds describing dwarf galaxies and with infall representing disk galaxies. In order to settle constraints for star formation timescales in DLAs, we use the ratios  $[\alpha/\text{Fe}]$  and  $[\text{N}/\alpha]$  in the comparison to the predictions of the models. These ratios in DLAs are only partially reproduced by the disk and dwarf galaxy models suggesting that the DLAs come from a variety of morphological types of galaxies and not only one. They also imply a typically long timescale for the star formation in these systems.

### 1. Introduction

Much effort has been devoted to the study of chemical abundances in the DLAs in the last few years (Lu et al. 1996, Centuri n et al 2000, Prochaska & Wolfe 1999, Ellison et al. 2001, Molaro et al. 2001). Most of these works is new observational data with subsequent analysis, which is based in comparison to known patterns of abundance and abundance ratios, mainly the ones observed in our Galaxy. These studies have already revealed some important characteristics of the DLAs which gives us some clues about their nature: their metallicity, given generally by  $[\text{Zn}/\text{H}]$ , lies in the range  $-2$  to  $0$  (Vladilo 1998, Lauroesch et al. 1996) suggesting different epochs for DLAs formation or different star formation histories; there is no sign of evolution in the metallicity of DLAs from N(HI)-weighted Fe abundance (Prochaska & Wolfe 1999, Prochaska & Wolfe 2000), although the metallicity content does decrease with redshift (Savaglio 2000); the  $[\text{Zn}/\text{Fe}]$  ratio is mostly above solar indicating the presence of dust depletion in these systems (Pettini et al. 1997); the  $[\alpha/\text{Fe}]$  pattern observed in DLAs roughly resembles that of metal-poor stars of our Galaxy (Pettini et al. 2000, Ellison et al. 2001), even though, there are some systems with values similar to those predictions by chemical evolution models for dwarf galaxies (Centuri n et al. 2000, Molaro et al. 2001).

Among these works, however, just in a few of them chemical evolution models are used in the comparison to the observational data (Prantzos & Bossier 2000, Matteucci et al. 1997). The predictions of the chemical evolution models are compared to absolute abundances (Prantzos & Boissier 2000) and abundance ratios (Matteucci et al. 1997). The abundance ratios are better suited for chemical evolution studies because, unlike absolute values, they do not depend heavily on model assumptions, but mainly on the stellar nucleosynthesis and on the adopted IMF. The  $[\alpha/\text{Fe}]$  and  $[\text{N}/\alpha]$  ratios can be used to settle constraints for star formation timescales due to the different timescales for the formation of these elements. While the  $\alpha$  elements are produced mainly in type II Supernovae (SNe II) in short timescales, the iron peak ones and N are produced in SNe Ia and in intermediate massive stars (IMS) in a larger timescale. There is a controversy about the observed pattern of the  $[\alpha/\text{Fe}]$  ratio in DLAs: while some authors detected patterns similar to that of the metal-poor stars of our Galaxy (Pettini et al. 2000, Ellison et al. 2001), others found values that resemble the chemical evolution of dwarf galaxies (Centurion et al. 2000, Molaro et al. 2001). This discrepancy may be associated with dust depletion.

We use, in this work, one-zone chemical evolution models to represent the DLAs, which predictions are compared to  $[\alpha/\text{Fe}]$  and  $[\text{N}/\alpha]$  ratios. The abundance of Zn, Fe and Si are corrected for dust depletion and robust statistical methods are used to establish the trends of the data. In this way, we try to make a complete study of the DLAs chemical evolution embracing the most important aspects that might affect these kind of analysis.

## 2. The Chemical Evolution Models

Due to uncertainties about the nature of DLAs, two types of one-zone model are used in a first study about chemical enrichment in these systems. A model with infall of pristine gas is used to represent the disk systems and another one with galactic winds for dwarf galaxies.

### 2.1. The disk model

The disk model belongs to the class of the models with one infall episode of pristine gas. We used the basic equations for chemical evolution, with a star formation rate (SFR) similar to the one used by Matteucci & François (1989), and a Salpeter IMF. The normalisation  $\tilde{\nu}$  of the star formation law is made with the solar position at 8 kpc and a galaxy age of 13 Gyr. The stellar yields for intermediate mass stars (IMS) come from Renzini & Voli, 1981 (hereafter RV81), models with  $\alpha_c = 0$  and 1.5. The yields from van den Hoek & Groenewegen (1997) for the IMS were also tested but the models with these yields produce less nitrogen than both  $\alpha_c = 0$  and 1.5 models of RV81 and consequently are not applied in this DLAs study. The infall rate decreases with time and the infall timescale and superficial mass density profile vary with the galactic radius.

We run several models with different values of  $r$ : 2, 4, 8, 14, 18 kpc.

### 2.2. The dwarf galaxy model

The dwarf galaxy model belongs to the class of models with galactic winds. The majority of the models used here are similar to the classic ones, in which a

wind is established in a time  $t_w$  when the thermal energy of the gas exceeds the potential energy.

A galaxy with 1 Gyr is represented by the models here applied, but there is also a model which represents a galaxy with  $10^7$  yr. The galaxy is inside a dark halo with a mass three times greater than the initial galaxy's baryonic mass. The star formation is continuous with a SFR proportional to the present mass of gas and characterised by the specific star formation rate  $\nu$  (the inverse of the star formation timescale), which varies in each model from 0.1 to  $19 \text{ Gyr}^{-1}$ . It is adopted a Salpeter IMF between 0.1 and  $100 M_\odot$ .

Besides the classic models with wind, an *early wind* model (Friaça 2000) is applied. Friaça (2000) proposed differential winds, due to SNeII, in dwarf galaxies in order to explain the  $[\alpha/\text{Fe}]$  below solar in the intercluster medium.

### 3. The Data

The observational data about the DLAs were collected from the literature and include chemical abundance (represented by  $[X/H] = \log(X/H)_{\text{obs}} - \log(X/H)_\odot$ ) of a variety of elements ranging from N to Zn, observed in the redshift interval  $0.6 < z < 4.4$  (for more details and references see Lanfranchi & Friaça 2001, submitted).

### 4. Analysis of the data

The observational data are analysed with robust statistical methods and compared to predictions of the chemical evolution models. In the statistical analysis we followed the approach described by Chiappini et al. (1999). We obtain, with the summary statistics of Cleveland & Kleiner (1975), three lines that summarise the trend of the data: MM (midmean), LSMM (lower semi-midmean) and USMM (upper semi-midmean). The final plots represent locally weighted regression (lowess) smoothes of the summary lines.

The trend lines and the points distribution are then compared to the predictions of the models described above focusing the  $[\alpha/\text{Fe}]$  and  $[\text{N}/\alpha]$  ratios. Due to the  $[\text{Zn}/\text{Fe}]$  generally above solar in our sample, what may be an indication of the presence of dust in the DLAs, we corrected the abundances of Zn, Cr, Fe and Si by dust depletion. The correction is based in the depletion pattern observed in our Galaxy together with the observed  $[\text{Zn}/\text{Fe}]$  in each system analysed (see Lanfranchi & Friaça 2001). The  $[\text{Si}/\text{Fe}]$  corrected for dust is then used as a tracer of the  $[\alpha/\text{Fe}]$  ratio in the comparison of the data to the predictions of the models, while  $[\text{N}/\text{S}]$  is used to represent the  $[\text{N}/\alpha]$  ratio. In this way, we obtain dust free (or almost free) tools to be compared with the models.

## 5. Application of the one-zone models to DLAs

### 5.1. Disk galaxy model

The disk models predictions for  $[\alpha/\text{Fe}]$  and  $[\text{N}/\alpha]$  ratio, using the RV81 yields with  $\alpha_C = 1.5$ , for different radius,  $r = 2, 4, 8, 14, 18 \text{ kpc}$  compared to the observed values in DLAs are shown on the figure 1.

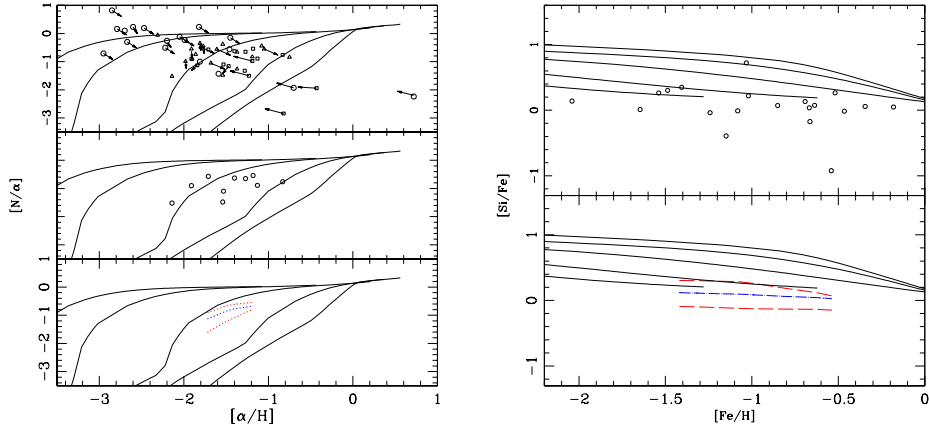


Figure 1.  $[N/\alpha]$  (left) and  $[\alpha/Fe]$  (right) observed in DLAs compared to the disk models. The  $\alpha$  elements abundance are represented on the top left panel by oxygen (open circles), sulphur (squares) and silicon (triangles). The  $[N/S]$  ratio free of dust is plotted in the middle left panel. The straight lines represent the grid of models for  $r = 2, 4, 8, 14, 18$  kpc (right to left and top to bottom). The statistical lines are the MM (long-dash - dot), USMM and LSMM (long dash) .

The observed  $[N/S]$  ratios with absolute values are centralised mainly between the lines for  $r = 4$  and  $14$  kpc, with a large number of systems around the  $r = 8$  kpc line, as indicated by the statistical trend lines. The lines trend are also similar to the models predicted behaviour: the ratio increases with  $[\alpha/H]$  rapidly in low metallicities and then becomes flatter.

The comparison between the observed  $[N/\alpha]$  in DLAs and the disk model predictions indicates that the observed values of this ratio represent a long timescale for the star formation in these systems for regions around the solar neighbourhood ( $4 < r < 14$  kpc).

There is a discrepancy, however, when the corrected  $[Si/Fe]$  ratio is used in the comparison to the models. The region of the models with  $r \approx 14 - 18$  kpc fits reasonably well the majority of the systems. The same behaviour is found for the statistical lines. They exhibit a trend similar to the models predictions and are located in the region around  $\approx 14 - 18$  kpc. Consequently, the comparison indicates that the observed values correspond to external regions ( $r > 14$  kpc) of disk systems, implying a long star formation timescale. A long and continuous star formation allows the iron peak group elements to be produced, giving rise to low values of  $[Si/Fe]$ .

## 5.2. The dwarf galaxy model

On the figure 2, the comparison between the predictions of the dwarf galaxy models with different specific star formation rates and the  $[\alpha/Fe]$  and  $[N/\alpha]$  ratios are shown.

The predictions for  $[N/\alpha]$  are compared to the observed ratios both in DLAs and dwarf galaxies. The  $\alpha$  elements abundance is determined only by oxygen

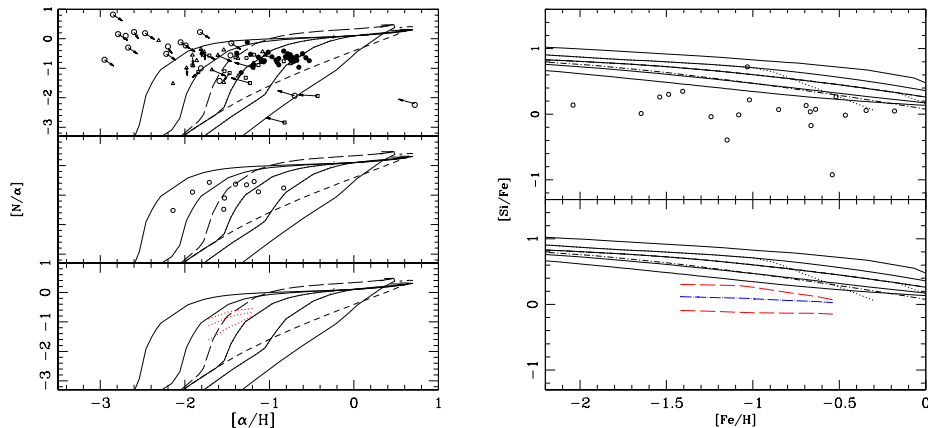


Figure 2.  $[N/\alpha]$ (left) and  $[\alpha/Fe]$ (right) observed in DLAs and dwarf galaxies compared to dwarf galaxy models. The  $[N/S]$  ratio is plotted in the middle left panel. The straight lines represent the grid of models with RV81 with  $\nu = 0.1, 0.3, 1, 3, 19 \text{ Gyr}^{-1}$  (left to right and bottom to top), the long dashed line a model with  $\nu = 1.0 \text{ Gyr}^{-1}$  and *early wind*, and the dashed line a model with  $\nu = 3.0 \text{ Gyr}^{-1}$  and  $M = 10^7 M_{\odot}$ . The statistical lines are the same as on the figure 1.

(circles) in dwarf galaxies while in DLAs sulphur (squares) and silicon (triangles) are also used to estimate it. The statistical lines are the same as on previous figure.

The observed  $[N/\alpha]$  in DLAs show a great dispersion, larger than that found for Galactic stars in the same range of metallicity and for dwarf galaxies. The different values of  $N/\alpha$  for a given  $\alpha/H$  can be explained with the difference between the formation timescale of N and  $\alpha$  elements. This fact can be seen in models with diverse values of  $\nu$  that go from almost quiescent star formation ( $\nu = 0.1 \text{ Gyr}^{-1}$ ) to an extreme rapid one ( $\nu = 19 \text{ Gyr}^{-1}$  for systems with  $10^9 M_{\odot}$ ). Most dwarf galaxies seem to require a specific star formation ( $\nu$ ) between 0.3 and  $3 \text{ Gyr}^{-1}$ , while the DLAs seem to need lower  $\nu$ :  $0.1 \leq \nu \leq 1 \text{ Gyr}^{-1}$  for classic wind models and  $\nu \approx 1 \text{ Gyr}^{-1}$  for models with *early wind*. The models with galactic winds reproduce all dwarf galaxy points but are unable to match some DLAs that fall totally out of the region delimited by these models.

In the case of the dwarf galaxy models too, there is a difference when the  $[Si/Fe]$  ratios is used in the comparison to the models. While for the  $[N/S]$  ratio, most of the observed values are fitted by models with  $0.3 \leq \nu \leq 1 \text{ Gyr}^{-1}$ , most systems and the statistical lines lie below the  $[\alpha/Fe]$  predicted by any model. Only the upper semi-midmean (USMM - dotted line) goes near the model with  $\nu = 0.1 \text{ Gyr}^{-1}$ . This fact implies a specific star formation  $\nu \leq 0.1 \text{ Gyr}^{-1}$ , which represents a long star formation timescale.

## 6. Conclusions

The comparison between the one-zone chemical evolution models for dwarf and disk galaxies and the observational data indicates that these models are able to reproduce only partially the  $[N/\alpha]$  and  $[\alpha/Fe]$  observed in DLAs. This fact suggests that these systems may represent various types of galaxies and not a single one. The observed abundance ratios also require long star formation timescale in both models. The discrepancy between the comparisons using  $[N/\alpha]$  and  $[\alpha/Fe]$  might be related to an underestimated correction for Si.

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